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Flexural Strength Reduction in Cemented Carbides

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Cemented carbides are hard materials used in tough materials machining as well as in situations where other tools would wear away. These are one of the most successful composite engineering materials ever produced. The advantage of cemented carbides is that their structure and composition can be engineered to have properties tailored to specific applications and operations. These materials allow faster and more precise machining and will leave a better surface finish. Carbide tools can also withstand higher temperatures than standard high speed steel tools. Considering their application and known range of properties, main disadvantage of cemented carbides is appearance of their sudden fracture during machining process. This is caused by the low toughness at dynamic rates and overcoming this problem is yet to be researched further. In order to understand these limitations and provide suggestions for the improved design of the material, combined experimental and numerical analysis is currently being performed. Cohesive strength values numerically determined using Dugdale cohesive zone model are compared to flexural strength obtained experimentally. Reduction in flexural strength was then analysed and explained, relating it to the flaw size on the tensile surface of the specimen.

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1. Introduction

Cemented carbides are composed of a metal matrix composite where carbide particles act as an aggregate and a metallic binder serves as the matrix. The process of combining the carbide particles with the binder is referred to as sintering. During this process the binder eventually will be entering the liquid stage and carbide grains remain in the solid stage. As a result of this process the binder is embedding/cementing the carbide grains and thereby creates the metal matrix composite with its distinct material properties. The naturally ductile metal binder serves to offset the characteristic brittle behaviour of the carbide ceramic, thus raising its toughness and durability. Such parameters of carbide can be changed significantly within the carbide manufacturer's sphere of influence, primarily determined by grain size, cobalt content and carbon content.

Cemented carbides have countless number of applications that can be grouped into three main areas: engineered components, wear parts and tools and tool blanks. These materials are hard materials used in tough materials machining as well as in situations where other tools would wear away. These are one of the most successful composite engineering materials ever produced. The advantage of cemented carbides is that their structure and composition can be engineered to have properties tailored to specific applications and operations. These materials allow faster and more precise machining and will leave a better surface finish. Carbide tools can also withstand higher temperatures than standard high speed steel tools.

In order to understand the fracture process occurring at relatively low load, which is basically the main disadvantage of these materials, combined experimental and numerical analysis is currently being performed.

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2. Materials

The grades used in this analysis contain tungsten-carbide (WC) and cobalt (Co) as the main elements, although small additions or trace levels of other elements can also be found as added to optimize their properties. Two different grades were used in this analysis and are classified according to their WC grain size:

- 4 μm average WC grain size, which is referred to as a fine grade (FG);
- 20 μm average WC grain size, which is referred to as a coarse grade (CG).

The series of tests on laser-cut cemented carbide specimens were previously performed in laboratory conditions at room temperature. Loading rate was varied from quasistatic of 1 mm/min up to dynamic of 5 m/s using the same procedure as outlined earlier in [1, 2]. Using standard equations, the fracture toughness, fracture energy, flexural strength and Young's modulus were determined according to linear elastic fracture mechanics.

3. Numerical model

After the fracture tests have been conducted and the relevant properties at initiation determined appropriate numerical model was developed capable of reproducing the obtained experimental results [3]. An implicit finite volume (FV) method was employed, as described by Jasak and Weller [4] and an open source software package called OpenFOAM [5] was used for calculation. The Dugdale cohesive zone model was used to describe the damage/failure process of the cemented carbide in terms of

the local material traction-separation relationship in the vicinity of the crack tip.

Two main parameters were specified in a cohesive description of material failure: the cohesive strength $\sigma_{\max}$ and the separation energy G. At first, the cohesive strength $\sigma_{\max}$ was assumed to be equal to the experimentally obtained value of the flexural strength σ_{f}. This returned too low ranges of initiation forces. The cohesive strength values were subsequently tried to be varied until the numerical initiation load matched the experiment, and that value was recorded as the true cohesive strength.

4. Results and discussion

Such obtained cohesive strength values resulted in good agreement of load-time traces between the numerics and the experiment [3] and they are given below in Table. As can be seen, using the previous Dugdale CZM expected flexural strength for the CG material should be 3000 MPa. However, the average value of experimentally determined flexural strength at quasistatic rate and room temperature was 2010 MPa with the initiation force of 5620 N.

TABLE

Cohesive strength of FG and CG cemented carbide.

Applied loading rate	$\sigma_{\max}$ [MPa]	
	FG grade	CG grade
1 mm/min	5080	3000
100 mm/min	4450	2590
0.3 m/s	3770	2240
1 m/s	3560	2080
5 m/s	2560	1460

In order to determine the reason where this discrepancy comes from, a study of the influence of a notch length on the initiation force was carried out. The force was calculated using the load at initiation method according to ASTM E1820-01 fracture standard [6]:

$$K_{Ic} = \frac{P_{\mathrm{in}} S}{b h^{1.5}} f(\alpha), \tag{1}$$

where $\alpha = a/h$, P_{in} is the breaking load and $f(\alpha)$ is a fitting function given by

$$f(\alpha) = \frac{3\alpha^{0.5}[1.99 - \alpha(1-\alpha)(2.15 - 3.93\alpha + 2.7\alpha^2)]}{2(1+2\alpha)(1-\alpha)^{1.5}}. \tag{2}$$

Using this method, the experimental initiation force falls within the region of 1.5–2 μm flaw size on the tensile surface of the rectangular specimen, as presented in Fig. 1.

The same phenomenon is observed for FG material and shown in Fig. 2. Expected flexural strength for the FG material should be 580 MPa. However, the average value of experimentally determined flexural strength at quasistatic rate and room temperature was 3390 MPa with the initiation force of 4210 N.

This confirms the hypothesis that experimentally determined strength was vastly underestimated due to the surface flaws of as big as 2 μm. These surface flaws have been observed on the specimen surfaces when examining their roughness, as shown in Fig. 3.

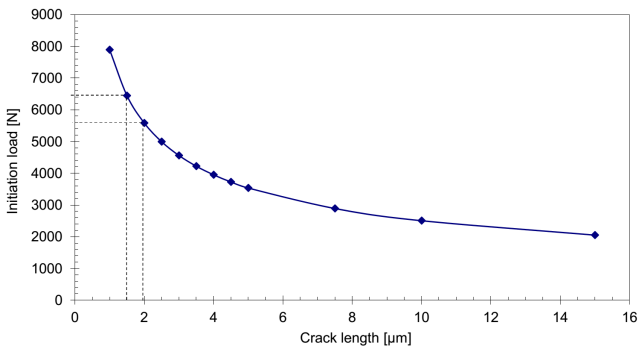

Fig. 1. Influence of the flaw size on the initiation force for CG specimen.

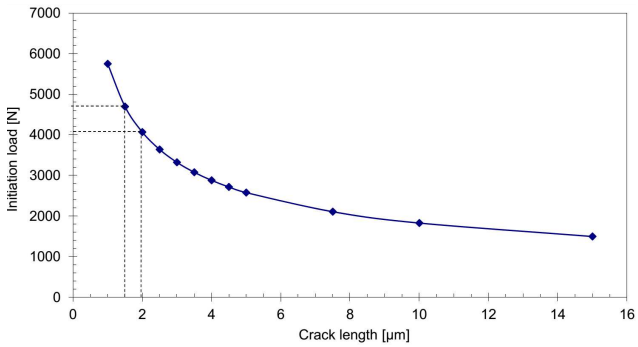

Fig. 2. Influence of the flaw size on the initiation force for FG specimen.

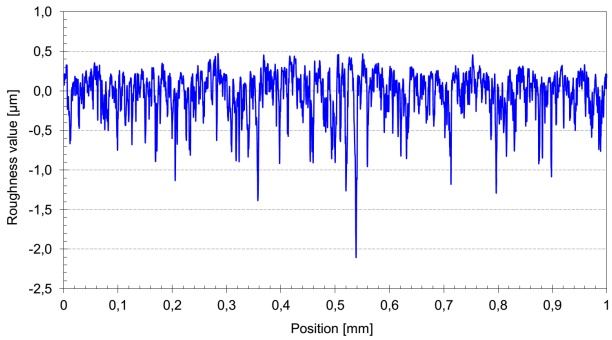

Fig. 3. Surface roughness observed on the cemented carbide specimen.

5. Conclusions

Analysis of the cohesive strength values obtained numerically by calibration of experimental results for two different grades of material at different loading rates was presented in this paper. The cohesive strength for each grade of material was previously determined across the range of loading rates used in the experiment, based on the impact speed and measured material properties that were provided as input parameters for modelling.

The computed cohesive strength was found to be much higher than the flexural strength obtained in the experiments. The reason for this is that experimentally determined strength was vastly underestimated due to surface flaws of as big as 2 μm which have been observed on the specimen surfaces.

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